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Nanotechnology, Biotechnology, and Information Technology: Implications for Future Science at EPA

A Workshop of the EPA Science Advisory Board

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NANOTECHNOLOGY, BIOTECHNOLOGY, AND INFORMATION TECHNOLOGY: IMPLICATIONS FOR FUTURE SCIENCE AT EPA

1.0 WORKSHOP BACKGROUND AND OBJECTIVES

The U. S. Environmental Protection Agency (EPA or the Agency) science programs have primarily focused on characterizing and managing risk from environmental exposure to chemical and biological, and physical stressors. Much of the Agency's ongoing work is based on managing historical sources of pollution. The Agency will continue working on these legacy problems, but it also faces opportunities and challenges from emerging technologies, products and services. EPA research programs currently look toward emerging environmental issues. However, science and technology continues to expand at unprecedented rates. This expansion has been referred to as a new industrial and economic revolution. It offers new opportunities, but also brings unanswered questions about their potential environmental risks and benefits. The present science and technology expansion coincides with flat to declining EPA science budgets for the foreseeable future. Accordingly, the Agency is faced with resolving existing environmental problems and developing new strategies for emerging concerns.

The EPA Science Advisory Board (SAB or the Board) has urged the Agency to develop a new science vision for human health and environmental protection that incorporates the latest scientific and technological advancements. Developments and emerging applications in Nanotechnology, Biotechnology and Information Technology over the past decade have been dramatic, and will continue into the foreseeable future. Advancements within and between these and other technologies will revolutionize industrial production and economic expansion, as well as the environmental sciences.

The SAB anticipates that as the Agency mission becomes more involved with Nanotechnology, Biotechnology and Information Technology products and services, the Board will be asked to provide advice to the Administrator on EPA science and research needs in these area. The primary objective of this workshop was to educate and inform the SAB, and to initiate a dialogue on the implications of these technologies for science and research advice to the EPA.

2.0 WORKSHOP OVERVIEW

Workshop participants included members of the SAB, the Clean Air Scientific Advisory Committee (CASAC), the Advisory Council on Clean Air Compliance Analysis (COUNCIL), and their committees. The workshop (*Agenda in Appendix A*) included invited presentations on Industrial Ecology, Nanotechnology; Bioproduction; Genomics; Sensor Networks; Large Scale Computing Applications; and Converging Technologies. Industrial Ecology was selected as a potential unifying theme for the six subsequent technology subjects.

Following the invited presentations, the speakers, invited subject matter experts *(Biosketches in Appendix B),* and workshop participants met in six breakout groups (*Breakout Group Assignments in Appendix C*) corresponding to the six technology areas. Following breakout group discussions (*Breakout Group Questions in Appendix D)* the workshop participants discussed the break out group results in plenary session.

This document summarizes: key findings and cross-cutting recommendations of the workshop(*Section 3.0*); the Industrial Ecology keynote address (*Section 4.0 and Appendix E*); and invited presentations and breakout group reports for Nanotechnology (*Section 5.0 and Appendix F*), Biotechnology – Bioprocessing (*Section 6.0 and Appendix G*), Biotechnology - Genomics (*Section 7.0 and Appendix H*), Information Technology – Sensor Networks (*Section 8.0 and Appendix I*), Information Technology – Large Scale Computing (*Section 9.0 and Appendix J*), and Converging Technologies (*Section 10 and Appendix K*).

3.0 KEY WORKSHOP FINDINGS & CROSS CUTTING RECOMMENDATIONS

The workshop demonstrated that advances and applications within and between Nanotechnology, Bioproduction, Genomics, Sensor Networks, Large Scale Computing, and Converging Technologies are occurring at an unprecedented rate. Such advancements offer substantial opportunities and challenges for EPA science and research planning and implementation and are provided in subsequent sections of this report. Further, they will undoubtedly impact the work of the Agency now and into the future. Key workshop findings and cross-cutting issues raised during the workshop are provided first, followed by the findings and recommendations for the specific technologies.

- Industrial ecology can be used as an evaluation framework for the development, application, commercialization, dispersal and potential environmental opportunities and challenges of materials and products resulting from new technologies.

- Industrial ecology can assist a shift from simple control and engineering solutions for product artifact manufacture and disposal; to evaluation of complex adaptive systems that incorporate real time adjustment and dialogue to address broader cultural impact of services.

- A strategic examination of how industrial ecology might integrate new technologies to assist the Agency in setting priorities for its most pressing problems may be warranted.

- Possible applications of nanotechnology and nanomaterials include their use in batteries and fuel cells, smart packaging and labeling, catalysts and separation membranes, paints and coatings, lubricants, composites, medical diagnosis and drug delivery systems, and self-replicating robots and assemblers.

- Aspects of nanotechnology and nanomaterials that require additional investigations include quantifiable estimates of their benefits, and their environmental, health and social impacts.

- Bioprocessing and the biorefinery concept can be used to produce a broad spectrum of products from engineered plants (e.g., starches, sugars, proteins, fibers, fuels, oils, antibodies and drugs) using economical, and environmentally friendly processes.

- Bioprocessing challenges include determining the environmental impact of biorefineries; bioprocess design; limited knowledge of metabolism and control mechanisms; and health and environmental effects of new classes of products.

- As an emerging science, -omics technologies (genomics, proteomics, metabolomics, etc.) offers significant potential to improve and refine EPA's mission of protecting human health and the environment.

- Obstacles to –omics based health and environmental applications include:

    - The lack of quantitative methods, full genomic sequences, reference and technical standards, and notation datasets for at-risk populations; and

    - Limited knowledge of cross-species generalizations; environmental generalizations, genes that confer environmental agent sensitivity, normal states, and damage indices.

- Embedded sensor networks include micro sensors, onboard processing, and wireless interfaces at very small scale that enable spatially and temporally dense environmental monitoring of previously unobservable phenomena

- Important challenges for sensor network applications include the development of sensors, platforms, software protocols, energy awareness and conservation, scaling and adaptation to variable resources and stimuli.

- Large-scale Computer applications can reduce the time for applying science in environmental decision-making, and have the potential to revolutionize how EPA might manage environmental decisions in diverse areas including:

- Computational chemistry and toxicology, modeling, monitoring, real time emergency response, econometrics; decision analysis; optimized economic growth; urban system management; and scenario analysis for economic, social and environmentally sustainable solutions under uncertainty.

- Potential environmental applications for converging technologies range from wearable sensors and computers to enhance awareness of health, environment, potential hazards, natural resources; to environmental networks of cheap, smart sensors that constantly monitor the condition of the environment.

- Advancements in new technology are occurring at unprecedented rates, making it difficult for government agencies to keep abreast of:

  - emerging developments;

  - science and technology skill mix needs;

  - priorities of new technologies against existing research strategies and multi year plans;

  - collaboration and interaction with other governments, federal agencies, science advisory committees, industry, academia, and the public.

- Emerging technologies can resolve complex environmental and energy problems with multiple and conflicting objectives, asymmetric information, short decision cycles, long analysis times, and few technically qualified people.

- Emerging technology development and applications require consideration and integration of social sciences (economics, decision sciences, etc.) to determine potential environmental benefits and impacts.

- The range of applications offered by new technologies that would benefit EPA's science and research activities is vast, and priorities should be strategically targeted to address the Agency most pressing priorities.

- Conventional toxicological and risk assessment approaches have largely been developed for chemicals and require modification for nanotechnology, biotechnology, and sensor deployment.

- The SAB might consider workshops that focus on strategic issues associated with the development and deployment of new technologies, as well as targeted workshops on novel applications of specific technologies for specific problems.

- The SAB might consider additional committees to address the development of new technologies.

In the closing discussion, participants noted that technology appears to be on the verge of altering the entire context of environmental protection and social welfare. Some questioned whether conventional risk assessment and regulatory structures are appropriate for the potential environmental challenges of emerging technologies. Others asked whether consideration needed to be given to altering our institutional structures to meet these challenges. Still others thought that the SAB might provide deeper thinking about where the EPA needs to be in ten years, and what it needs to do to get there.

In closing remarks Dr. Granger Morgan, Chair of the SAB, noted that the topics and recommendations emerging from the workshop were diverse. He observed that specific recommendations were valuable, but that real impact of the workshop was a *diffusion process*. That is, workshop participants take what they have learned back to their offices, and incorporate new thinking into their work. For the SAB, this means new ideas in reviewing EPA projects, programs, planning documents, and the science budget. He stated that the ideas discussed at this workshop will set the stage for additional SAB deliberations regarding how to best advise the Agency on the use of new technologies in its science enterprise.

4.0 KEYNOTE ADDRESS SUMMARY

4.1 Industrial Ecology Principles: A Unifying Theme for Environmental Applications of New Technologies -- *Dr. Braden Allenby, School of Engineering, Arizona State University (See Slides Appendix E)*

Industrial Ecology is a systems approach to environmental analysis. It addresses industrial emissions, specific products, and the complex network of services, products and activities that make up the economy. Industrial ecology can guide holistic thinking about environmental problems. The need for guiding principles is illustrated by the rapid societal changes being brought about by advancements in technology. Technology causes fundamental changes, and the rate of change currently exceeds the ability of governments to react in a timely manner. Therefore, timely decisions and specific courses of action are preempted by rapid societal change, which often lacks systematic consideration of holistic environmental consequences. Dr. Allenby discussed two case studies that demonstrated the need to shift environmental analysis and problem-solving away from simple command and control of product manufacture and emissions, and towards complex adaptive systems. Several key points follow, and Dr. Allenby's complete slide presentation is shown in Appendix E.

- Traditional environmental science and engineering has been directed toward controlling physical environmental impacts associated with energy consumption and toxic products related to artifact manufacture and disposal.

- Although less intuitive and much less studied, cultural environmental impacts from such services may be potentially large. Critical thinking is required to resolve ethics, fundamental changes in human cognition and perception through computers and information technology.

- Industrial ecology principles (earth systems engineering and management related to design engineering, governance and theory) provide a unifying theme for environmental applications of new technologies.

- Bothersome Questions for the SAB to consider

  - Should EPA have a Technology and Science Advisory Board, and should an Industry Advisory Board be added?

  - Should EPA become a competency that diffuses itself throughout government?

  - How will EPA and government generally, develop the ability to engage ialogue with, rather than regulate, complex human/natural systems?

- How will EPA develop the ability to operate on a time cycle that aligns with the phenomenon for which it is responsible?

- How will EPA function as its core conceptual foundations (environment, wilderness, nature) become increasingly contingent, and change substantively over shorter time periods?

- What is EPA's role as the world increasingly becomes a product of human design?

- How does EPA avoid becoming more and more effective, at less and less important tasks, as environmental impacts increasingly become a function of strategic and non-environmental technological and business decisions?

5.0 NANOTECHNOLOGY

5.1 Invited Presentation: ***Nanotechnology*** **–** *Dr. Roland Clift, Centre for Environmental Strategy, University of Surrey (See Slides Appendix F).*

Nanotechnology is an emerging technology based on solid particles in the size range of 1-100 nm (a nanometer is 1X 10^{-9} meter and comparable in size to viruses) where properties are determined by size and surface area rather than bulk properties. A member of the Royal Society/Royal Academy of Engineering Working Group on Nanoscience and Nanotechnologies, Dr. Clift provided a European perspective based the Working Group report *Nanoscience and Nanotechnologies: Opportunities and Uncertainties* (2004). He discussed possible applications including the use of nanomaterials in batteries and fuel cells, smart packaging and labeling, catalysts and separation membranes, paints and coatings, lubricants, composites, and medical diagnosis and drug delivery systems, and self-replicating robots and assemblers. He focused his remarks on three areas of concern: quantifiable benefit estimates; health and environmental impacts; and social impacts of new and emerging technologies. Several key points follow, and Dr. Clift's complete slide presentation is shown in Appendix F.

- Systematic life cycle assessments of the benefits and risks of nanotechnology have not yet been conducted, the potential health and environmental impacts are uncertain, and social impacts are unknown.

- Conventional hazard and risk endpoints may provide a basis for regulation, but standard tests (e.g., toxicity, persistence, bioaccumulation) may not be applicable for nanomaterials due to surface property alterations at the nanoscale.

- Toxicity information is lacking, and regulation must be based on likely nanoparticle exposure scenarios (e.g., vehicle emissions, sun screens, cosmetics, and combustion).

- The precautionary approach suggests a moratorium on certain nanotechnology applications (e.g., fuel additives, bioremediation of groundwater, and end-of-life product disposal). However, nanoparticles are likely to be made at point of use, making arguments for a production moratorium irrelevant.

- The Royal Society/Royal Academy of Engineering Working Group recommended that Europe conduct horizon scanning of emerging technologies by asking what impacts and regulatory issues might arise.

5.2 Nanotechnology Breakout Group Report

The breakout group participants (Appendix C) discussed current government and industrial initiatives and projects, applications, and possible risk assessment and risk management issues regarding nanomaterials. The following points were prepared for the plenary presentaion and discussion.

<u>Basics</u>

- Nano-size and nano-materials have to be considered together.

- Life cycle assessments should consider what is being made, where it goes, and where it ends up?

- Presently, over 200 companies worldwide are involved in making nanoproducts.

- Nanotechnology development may be going the way of uncritical praise and optimism, and there may be lessons to be learned from earlier controversies (e.g., genetically modified organisms and nuclear power).

Opportunities

- Nanotechnology application holds great promise for electricity transmission, solar conversion, catalysis, sensors, treatment and purification technologies, and the remediation of hazardous wastes.

Challenges

- Public discussion on nanotechnology should be encouraged and amplified.

- Life cycle assessment should be applied to nanomanufacturing and nanoproduct footprints.

- Standards and measurements (testing protocols) need to be developed for nanotechnology research.

Future Role of SAB

- SAB can help identify the most urgent environmental problems (SAB nanotechnology review, need for environmental nanotechnology science plan, etc).

- Should SAB help EPA reconsider its relationship to industry (Being informed enough to know what will be happening; doing collaborative research)?

6.0 BIOTECHNOLOGY – BIOPROCESSING

6.1 **Invited Presentation***: **Bioprocessing: Opportunities and Challenges – Dr. Harold Monbouqette**, University of California – Los Angeles (See Slides Appendix G)*

Bioprocessing exploits a broad universe of metabolic processes and enzyme activities to synthesize specialty and commodity chemicals. The biorefinery concept is closely associated with bioprocessing, but provides a commodities development perspective. Presently, there is a diverse enzyme toolkit available to industry. Of approximately 30,000 known enzymes, about 3000 have been well characterized, and about 300 are commercially available. Accordingly, available techniques allow engineering of plants, microbes and enzyme systems for production of chemicals using economical, and environmentally friendly processes. Bioprocessing can be used to produce a broad spectrum of products from engineered organisms, including starches, sugars, proteins, fibers, fuels, oils, antibodies and drugs. Dr. Monbouquette focused on several applications in his area of expertise. Several key points follow, and his complete slide presentation is shown in Appendix G.

- Bioprocessing and the biorefinery concept exploit metabolic processes and enzyme activities for the production of specialty and commodity chemicals.

- Examples include: production of carotenoid pigments from genes cloned into *E. coli*; biosynthesis pathways for aspartame, melanin, and indigo; and the integration of enzymes into chemical synthesis processes to reduce environmental impacts.

- Bioprocessing has the potential to provide new products including chiral drugs, flavorings, aromas, herbicides and pesticides, hyperthermophilic glycoside hydrolases for oil and gas well fracturing. New systems may be needed to assess environmental impact of these processes and products including, for example, methods for detecting potential endocrine disrupting chemicals (EDCs).

- Bioprocessing presents several opportunities beneficial for the environment including: genetically modified organisms to synthesize chemicals from renewable resources; and enzymes to improve selectivity and yield of industrial chemical synthesis steps thereby reducing environmental impact.

- Challenges presented by bioprocessing include determining the environmental impact of biorefineries; bioprocess design; limited knowledge of metabolism and metabolic control mechanisms; and health and environmental effects of new classes of products and processes.

6.2 Bioprocessing Breakout Group Report

The breakout group participants (Appendix C) discussed potential bioprocessing applications, as well as risk assessment, risk management, and policy needs. The following points were prepared for the plenary presentation and discussion.

<u>Opportunities</u>

- Switching from a petroleum-based economy to bioproduction provides opportunities to reduce the toxicity of industrial waste and byproducts.

- Bioproduction offers opportunities to use agricultural products and waste materials (e.g., agricultural waste) in fermentation processes.

- Small community-based systems are important to allow innovations in bioproduction at the local scale.

- Metabolic engineering using recombinant DNA technology has the potential to improve production of chemicals by host organisms, and allow production of new chemicals.

- Currently, some biomass (e.g., cellulose) cannot be effectively used in conventional bioproduction. Gasification, followed by biosynthesis provides a near term opportunity for effective use of cellulitic biomass as raw materials in production processes.

- Technology is being developed to use biomass such as grass, wood and waste material in bioproduction processes.

- Bioproduction offers opportunities for animal waste reduction and more efficient use of nutrients (e.g., phosphorus fed to chickens).

- In the near term, advancements in viable, environmentally safe technology should be a priority (e.g., use of systems in landfills to remove methane).

- How EPA might regulate the use of new technologies is a key issue. Science needs and regulatory impediments should be addressed for regulating genetically modified organisms used in and products from bioproduction.

- EPA should consider incentives to advance the state of the science through innovative approaches like credit trading programs for waste generators.

- EPA needs to catalyze formation of university/industry/other federal agency partnerships to conduct innovative research and development and more effective integration of bio-based green chemistry work.

- EPA should articulate research needs and provide more external support for research and training of graduate students in emerging areas.

- EPA should develop multidisciplinary approaches for life cycle analysis. To encourage innovation, a framework not a standard protocol is needed.

Challenges

- Environmental problems associated with more intensive agricultural production in different crops must be considered.

- Energy and fertilizer demands in agriculture are high.

- Degradation of soil, displacement of wildlife, and water quality problems (hypoxia caused by nitrogen and phosphorus runoff from farm fields) must be considered.

- Tradeoffs between environmental benefits of bioproduction and benefits of reducing the intensity of agriculture (e.g., taking marginal land out of production, converting land to wetlands) should be evaluated.

- Research is needed to understand ripple effects of bioproduction through land use and social and economic systems (these may be very large).

- Potential environmental effects of accidental releases of recombinant DNA must be considered.

- Biosafety guidelines are needed for bioproduction technologies.

- Studies of genetically modified organisms used in more open processes such as biorefineries should be conducted to quantify environmental benefits and evaluate benefits versus risks.

- Regulatory authority for genetically modified organisms between agencies should be clarified.

- New toxicology tools should be developed to examine bioproduction.

- EPA should develop good management practices for testing new technologies to determine whether they may cause environmental problems.

- Good sensors are needed to conduct assessments of new technologies.

Future Role of the SAB

- SAB should continue to hold technical workshops like this one in order to anticipate emerging issues.

- SAB should encourage EPA to work closely with the science advisory committees of other government agencies, particularly DOE, USDA, and Commerce on bioproduction issues.

7.0 BIOTECHNOLOGY – GENOMICS

7.1 Invited Presentation: *Towards genomics-based analyses of environmental agent impacts on biological systems* – *Dr. Bruce Aronow, Cincinnati Childrens Hospital (See Slides Appendix H)*

The term *genomics* specifically refers to the study of the structure, activity and functions of genes. It includes gene regulation, mRNA expression, and cell-type specificity. Genomics is often imprecisely used to cover other *"-omics"* sciences such as physiomics (tissue dynamics, systems biology, and the outcome in clinical populations) and proteomics (protein expression, structure, interactions, localizations and pathways). Dr. Aronow focused his presentation on using genomics to assess environmental effects on biological systems, with emphasis on mouse and human models for colon cancer. Several key points follow, and his complete slide presentation is shown in Appendix H.

- Genomics can provide new tools to assess the impact of environmental agents.

- Systems biology approaches will assist the integration of genomics data and analyses into human health and environmental assessment scenarios.

- Technical barriers currently present obstacles to genomics-based health and environmental monitoring. These include:

    - Lack of quantitative methods, full genomic sequences, reference and technical standards, and notation datasets for at-risk populations;

    - Limited knowledge of cross-species and environmental generalization, genes that confer environmental agent sensitivity, normal states, and damage indices.

- Two case studies were presented using human and mouse central nervous system genes; and comparative transcriptional profiling for mouse and human colon cancers.

- The case studies demonstrated the classification of human tumors based on behavior of developmentally regulated mouse gene orthologs that have implications for outcomes to individuals.

7.2 -Omic Sciences Breakout Group Report

The breakout group participants (Appendix C) discussed potential genomic applications, as well as risk assessment, risk management, and policy needs. The following points were prepared for the plenary discussion.

<u>Opportunities</u>

- -*Omics* technology is not limited to genomics, but includes proteomics, metabolomics, etc.

- As an emerging science, -*omics* technology offers significant potential to improve and refine EPA's mission of protecting human health and the environment.

- Complexity, costs, and effective implementation of -omic technology demands new models of research partnerships, both within and across federal agencies, and with external research communities and sectors.

- Engage ongoing efforts in NAS, OECD and others developing application plans for biotechnology.

- -O*mics* technology has value for EPA's mission (e.g., identifying susceptible populations, surveillance analysis, prioritization, reduced use of animals fro testing).

<u>Challenges</u>

- EPA should develop a Framework (Multi-Year Plan) focused on implementation of -*omics* technology that covers: partnerships; attraction, retention, and training of human resources; bioinformatic needs and integration with other databases; systems biology and integrated modeling capacity; development of performance standards; commonality of methods; consistency of performance/baseline measurements; external data submission; and training sets for interpretation.

- The Multi-Year Plan research plan should be developed in keeping with OMBs Program Assessment Review Tool (PART).

Future Role of SAB

- Consider interactions with other agency Science Advisory Boards, and examine new models of cross-agency funding and resource sharing, funding needs, ethics, and the value of *-omics* technology to key customers.

- Consider priorities of *-omics* technologies relative to other multi-year plans.

8.0 INFORMATION TECHNOLOGY – SENSOR NETWORKS

8.1 Invited Presentation: *Wireless Sensor Networks for Environmental Monitoring* – *Dr. Deborah Estrin, University of California – Los Angeles (See Slides Appendix I)*

Embedded sensor networks include micro sensors, onboard processing, and wireless interfaces at very small scale to monitor phenomena up-close; enable spatially and temporally dense environmental monitoring; and reveal previously unobservable phenomena. Dr. Estrin focused her presentation on ecological and contaminant transport applications, as well as regional and global possibilities for sensor network development. Several key points follow, and her complete slide presentation is shown in Appendix I.

- The emerging technologies discussed in this workshop offer opportunities for development of new sensor networks to observe, monitor and model various functions.

- The specific embedded sensor networks applications discussed included contaminant transport in soils, plankton dynamics in marine environments, and ecosystem processes.

- *In situ* Sensing will transform observations of spatially variable processes in heterogeneous and obstructed environments. Example applications include a locally dense surface and subsurface sensor network to observe soil nitrate transport; spatial and temporal distributions of algal blooms in coastal ecosystems; ecosystem processes such as microclimate monitoring, image and acoustic sensing, and infrastructure mobility.

- Important challenges for sensor network applications include sensors, platforms, software protocols, energy awareness and conservation, scaling and adaptation to variable resources and stimuli.

- Heterogeneous sensor networks of small linked robotic sensors that host higher-end sensors are needed to enable adaptive, fidelity–driven, three-dimensional sampling.

- The development of embeddable sensor networks and multi-scale observation and fusion networks have broad relevance to global issues.

8.2 Sensor Networks Breakout Group Report

The breakout group participants (Appendix C) discussed the rapid advancement of sensor network technology, and possibilities for cheap, small sensors capable of multi-factor analysis, data-relay, and network integration. Future applications might well include laboratories on a chip, and mass spectrometers the size of sugar cubes. The breakout group focused their attention on new technologies, demonstration projects, and prepared a set of network development technology principles, challenges and future role of the SAB for presentation and discussion at the plenary session.

Principles for Sensor Network Development

- Affordability (The National Ambient Air Monitoring Strategy is one approach for redesign within existing annual total costs (http://www.epa.gov/ttn/amtic/files/ambient/monitorstrat/allstrat.pdf).

- Problem-oriented applications focused on solving environmental problems of critical importance to EPA's mission and regulatory mandate.

- Technologies that are realistically and demonstrable in the near-term

- Partnerships should be developed to:

  - Ensure commercial viability of new technologies to capitalize on corporate investments made by industry;

  - Utilize existing data networks in the federal, state, tribal, and local sectors;

  - Partner with other government agencies engaged in basic and applied sensor-network research to leverage research funding and capabilities.

- Focus on multi-use, multi-pollutant sensors and applications that include sensors for ecological, biological and human health applications.

- Specify interoperability and comparability of data by design and select data networks and embedded sensors that are interoperable with analytical data equivalence.

- Employ multi-layer, large to small scale sensor networks (e.g.,satellite imagery and smaller-scale remote-sensing to local on-site sensors).

- Ensure data are easily interpretable and include data visualization techniques (i.e., visual display of dense, complex quantitative and qualitative information from embedded sensor networks), leading to clear unambiguous interpretation.

- Demand high performance and reliability over time (i.e., consistent and accurate data transmission without need for recalibration); robustness (i.e., imperviousness to adverse in situ conditions); value and affordability; adaptability; sustainability (both technical and institutional); real-time data transmission; and portability.

- Pursue a "systems" approach for sensor networks in complex ecosystems.

- Deploy "early-warning" systems throughout the country that are relatively inexpensive, widespread networks that direct attention to deeper problems as they develop.

Challenges

- Network design is perhaps more challenging than actual sensor development, and highly dependent on the specific objective and network scale.

- Wide ranging potential applications were discussed including: mercury in air and water in the Eastern U.S.; Mississippi River watersheds and Gulf of Mexico dead zone; the Great Lakes; Chesapeake Bay; TMDLs in Northwest redwood region; and CAFOs in the San Joaquin Valley.

Future Role of the SAB

- A workshop on the use of new sensor network technology in the context of two or three Agency problems (e.g., Great Lakes). The developers as well as EPA problem identifiers are necessary to formulate templates and networks in the context of the Agency strategic and multi-year plans. Such activities should be directed toward developing a clear conceptual model that delineates what the system looks like and how it works, to appropriately use sensors in hypothesis testing. Adaptive management would then allow continued use of the network.

9.0 INFORMATION TECHNOLOGY – LARGE SCALE COMPUTING

9.1 Invited Presentation: *Information Technology (IT): Implications for Future Science at EPA* – *Dr. Gregory McRae, Massachusetts Institute of Technology (See Slides Appendix J)*

Information Technology (IT) includes a spectrum of computers, databases, communications, sensors, visualizations, algorithms, and their management. Information technology can also reduce the time for applying science in environmental decision-making. Therefore, advances in information technology have the potential to revolutionize how EPA might manage environmental decisions. Dr. McRae focused his presentation on driving forces for change, new dimensions of working in teams, routine visualization of complex phenomena, and global environmental problems. Several key points follow, and his complete slide presentation is shown in Appendix J.

- Real and perceived environmental risks exist, and IT can help develop proper science and policy responses and revolutionize how EPA manages environmental risks.

- Computers, databases, communications, sensors, visualization, algorithms, and their management can reduce the time for applying science in environmental decision-making.

- Forces driving information technology development include bandwith, optical networks, remote access, and routine visualization of complex environmental problems.

- IT can resolve complex environmental and energy problems which often involve multiple and conflicting objectives, asymmetric information, short decision cycles, long analysis times, and few technically qualified people.

- Air Quality, Genomics, and Bioinformatics are areas where IT has been used with varying degrees of success in environmental problem solving.

- Data for environmental problem solving are not often integrated, may lack useful uncertainty estimates, are variously documented, and of variable quality. Solving these data problems would enhance the pragmatic use of IT in environmental decision-making.

- Moving away from conventional compliance assessment to inverse modeling and deterministic control strategy designs would minimize control costs and maximize air quality, minimize exposure to pollution, and minimize risk of exceedances.

- Solving these problems requires cost-effective monitoring systems using advanced technology.

- The development of novel inexpensive sensors and innovative deployment would assist the detection and resolution of environmental problems before they become acute.

- Greater use of life cycle assessment models like MIT's Environmental Evaluation Model would assist the development of optimized design and control strategies for new industrial products and processes.

- Dr. McRae posed several needs and questions for the SAB's consideration.

    - There is a critical need for multimedia integration of databases and models to prevent problems such as MTBE contamination.

    - A most critical issue is how to find and employ people with appropriate training and expertise in information technology

    - Information technology is a critical enabling resource and asked if EPA needs a Chief Technical Officer or Chief Information Officer?

    - How can database access be improved for use in decision- making?

- How can more science be integrated into control strategy design processes?

9.2 Large Scale Computing Breakout Group Report

The breakout group participants (Appendix C) discussed possible applications of information technology with an emphasis on supercomputing applications, and prepared the following points for presentation and discussion at the plenary session.

Opportunities

- Information technology is crucial to advancement of computational chemistry, computational toxicology, air quality modeling, biochemical modeling, groundwater transport and remediation, watershed management, surface water quality and hydrodynamics.

- Additional opportunities include the use of information technology in real time emergency response; multimedia, ecological, and respiratory airway modeling

- Similarly, information technology can be used to enhance the applications in: econometrics; decision analysis; optimized economic growth; urban system management; and scenario analysis for economic, social and environmentally sustainable solutions under uncertainty

Challenges

- Support and educate a diverse generation of scientists and engineers capable of using innovative and state-of-the-art large scale computing applications.

- Data availability, access, and quality

- Model evaluation

- Computing capability

- Practical methods for large-scale optimization

- Prioritize resources to resolve uncertainties

- Collaboration between Agencies

Future Role of the SAB

- Create an advisory panel to prioritize opportunities and identify challenges and outline necessary resources

- Organize a "supercomputing workshop"

- Put together a "supercomputing road map" of needs to be considered for EPA

- Inclusion of other Agencies with supercomputing capabilities/interest

- Engage industry in the mission so they can share experiences and EPA can learn new technologies

10.0 CONVERGING TECHNOLOGIES

10 .1 Invited Presentation Summary*: Converging Technologies (NBIC) –* *Dr. William Bainbridge, National Science Foundation (See Slides Appendix K)*

Converging technologies represents a movement focused on the unification of science and technology, and is defined by interactions between Nanotechnology, Biotechnology, Information Technology, and Cognitive Sciences (often referred to as NBIC or convergence). Dr. Bainbridge focused his presentation on general principles and applications of convergence. Several key points follow, and his complete slide presentation is shown in Appendix K.

- Opportunities for science and technology convergence are based on shared methodologies which provide opportunities for developing transformative tools

- One-way convergence is taking an idea, tool or discovery from one field and applying it to another.

- Mutual convergence is when scientific theories and models are applied across different fields facilitating exchange.

- The principles of convergence include:

  - Material unity of nature at the nanoscale;

  - Technology integration from the nanoscale;

- Key transforming tools for NBIC;
- The concept of reality as a closely coupled complex hierarchical systems;
- Goals to improve human performance.

- Application areas for improving human performance using converging technologies have emerged including:
  - The expansion of human cognition and communication;
  - Improving human health and physical capabilities;
  - Enhancing group and societal outcomes;
  - Strengthening national security and competiveness, and
  - Unifying science and education

- Several converging technologies application areas were presented.
  - Spatial cognition through wearable sensors and computers to enhance awareness of health, environment, potential hazards, natural resources, etc.
  - National security applications including information rich fighter systems, intelligence gathering systems, and effective counter measures for biological, chemical, radiological and nuclear attacks
  - Agriculture and food industry applications to increase yields through networks of cheap, smart sensors that constantly monitor the condition of plant, animal and farm products.
  - New categories of materials, devices and systems for use in manufacture, construction, transportation, medicine, emerging technologies and scientific research.
  - Processes of the living cell, which is the most complex known form of matter with nanoscale components.
  - Principles of advanced sensory, computational and communications systems integrating diverse components into a ubiquitous, global network

- Structure, function, and occasional dysfunction of intelligent systems, most importantly the human mind.

10.2 Converging Technologies Breakout Group Report

The breakout group participants (Appendix C) discussed actions the SAB might take with respect to converging technologies. The breakout group focused their attention on priorities and prepared the following points for presentation and discussion at the plenary session

Highest priority SAB Actions

- New Reducing Risk/Over the Horizon-type report focusing on where existing regulatory science and policy lags behind new technology issues.
- Address Administrator's priorities by identifying opportunities for converging technologies (e.g., mercury).
- Review EPA's Science Inventory for activities related to converging technologies and identify gaps and opportunities.
- Develop low-cost exploratory steps to increase fluency in converging technologies and influence exchange within and between EPA, other Agencies, and stakeholders.
- Develop joint proposals with other Federal Agencies

Other Possible SAB Actions to Highlight Opportunities and Address Challenges

- White paper on challenges and opportunities-- addressing national and global dimensions
- Advise on EPA's plans to expand its skill set
- Catalyze multi-disciplinary collaboration -- "Synthesis U," rotational assignments, fellowships
- Data issues -- meta data needs
- Address EPA's gap in cognitive and behavioral science
- Address environmental education, risk perception, risk communication issues